DEVELOPING A WORKFLOW FOR STANDARD-BASED WIND ANALYSIS

Early design stage wind analysis tool that incorporates the Australian Standard: AS/NZS 1170.2

SARAH XAVIERA,
University of New South Wales, Sydney, Australia
s.xaviera@student.unsw.edu.au

Abstract. In recent years, the notion of microclimate, that describes thermal conditions, wind, and sunlight has become an increasingly significant concern in architectural design, especially as the performance of buildings are increasingly subject to various mandatory rating systems during approval processes. Consequently, there has been increasing interest from the architectural discipline in analysing design models through microclimatic lenses, and particularly the effect of wind. While there are a number of wind analysis tools available for architects, such as ANSYS CFX and Autodesk Vasari, most of these tools are based on the concept of Computational Fluid Dynamics (CFD), whereas those that are based on the rules and calculations of local government wind loading standards are still rare. The paper aims to create a workflow for a wind analysis tool that informs users of the impact of wind load on an architectural design through the rules and calculations of the Australian government standard: AS/NZS 1170.2. This paper focuses more on a workflow that allows users to calculate the internal and external pressures created by the wind and to visualize the effects on the architectural model. This paper will also assess the problems associated with the workflow and discuss suggestions for future improvements.

Keywords. Wind Load; Wind analysis; Australian government standard; Visualization and Optimization

1. Introduction and Motivations

Understanding the effects of microclimate in relation to buildings, particularly the impact of internal and external wind loads, is becoming increasingly important in the architectural discipline as the importance of building performance assessment during approval processes grows. Usage of wind analysis tools have long been implemented in architectural design to simulate wind phenomenon in digital models, providing visual and numeric information that can be used by architects. However, most of these tools are based on the calculations of Computational Fluid Dynamics (CFD), a branch of fluid mechanics that analyzes and solve their problems through the calculations of fluid flows (Kaijima, Bouffanais, Willcox, 2013). Tools based on the rules and calculations as stated by the local government standard remain rare.

CFD-based wind analysis tools such as Autodesk Vasari and ANSYS CFX has been available since the early 1980s with its development and accuracy increasing over the years. While CFD has become the tool that architects use most frequently to assess their architectural models, these tools are limited as they require high computing power, adequate time to run simulations and the input of experts to set up the simulations correctly causing them to be very expensive and sometimes less accessible (Salim & Moya, 2012). The AS/NZS 1170.2 are able to assess local pressure, the wind pressure on small areas of the building, which the CFD fails to assess as the scale is small and locally generated turbulence plays a significant role (Holmes, 2015). Therefore, the aim of this research is to create a workflow that better informs the users of the impact of wind load on the design model through applying the rules of the AS/NZS 1170.2.

2. Research Aims

Wind analysis tools that are based on the concept and calculations of Computational Fluid Dynamics (CFD) are commonly available for use, however, there are no analysis tools that are based on the rules and calculations of the Australian Standard: AS/NZS 1170.2. Wind analysis through the Australian Standard has become necessary in the design process as it is part of the Building Code of Australia to reduce structural failures. The lack of standards-based wind analysis tools limits the accessibility of this knowledge to experts such as engineers. As a result, architects rely heavily on the input of experts to ensure designs are analysed correctly. Furthermore, the lack of these types of wind analysis tool also led to the overuse of CFD software even in situations that does not require them causing unnecessary time and money loss.

This project aims to address this problem by designing a workflow for a wind analysis tool to guide users with minimal knowledge on the AS/NZS 1170.2 in the analysis of design models against the standard. Analysing the building design models against a wind analysis tool with the AS/NZS 1170.2 calculations aims to assist users to analyse even the local pressures on the buildings. This proposed new workflow is intended for the early design stages, when the design form of the building is still simple, reducing the time and costly remediation that can be incurred by poor wind performance in latter design and construction stages. The project will use the algorithmic modelling plugin, Grasshopper and Python to develop the workflow for the standard-based wind analysis tool.

3. Research Questions

Following the problems and gap as listed above, it is evident that creating a standard-based wind analysis tool is unique and beneficial so that non-experts and people who does not have access to the standard, could also analyse the building design models against the rules of the standard. Thus, the research raises the research question: *"How can the Australian Standard, AS/NZS 1170.2, be accessible to non-engineers like architects to reduce the use of CFD software in situations that does not require them by implementing computational tools?"*

4. Methodology

Drawing from the existing knowledge on the Australian government standard on wind actions, wind analysis and wind engineering, the research develops a workflow that could inform users with minimal knowledge on the Australian standard: AS/NZS 1170.2 of the impact of wind load on architectural design models through the rules of the standard. This research project adopts an action-based research method, an experiential method that uses the framework of first identifying the problem and creating a solution, carrying out the solution, evaluating and reflecting on the solution before creating the new solution (Gabel, 2017), as an overarching method to develop and test the workflow. The workflow aims to help increase the users' understandability of the standard through the computational tool, Grasshopper.

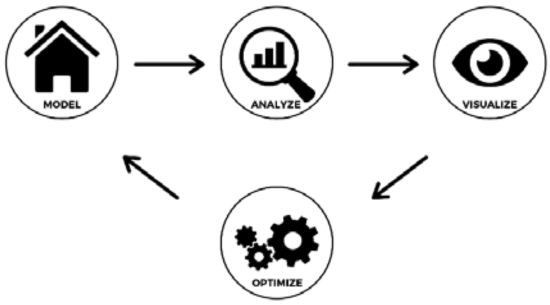

Figure 1. Workflow of the Wind Analysis Tool

In order to develop the workflow, test scripts were created to allow architectural design models to be imported into Grasshopper by the user before having the impact of the wind load on the model calculated and analysed. After an evaluation of the initial test scripts and solving several problems generated from it, the second step of the development allows coloured voxel grids to be generated on the walls of the buildings to represent the local pressure acting on the building as stated in the clause under local pressure factor in the standard (Standards Australia, 2011).

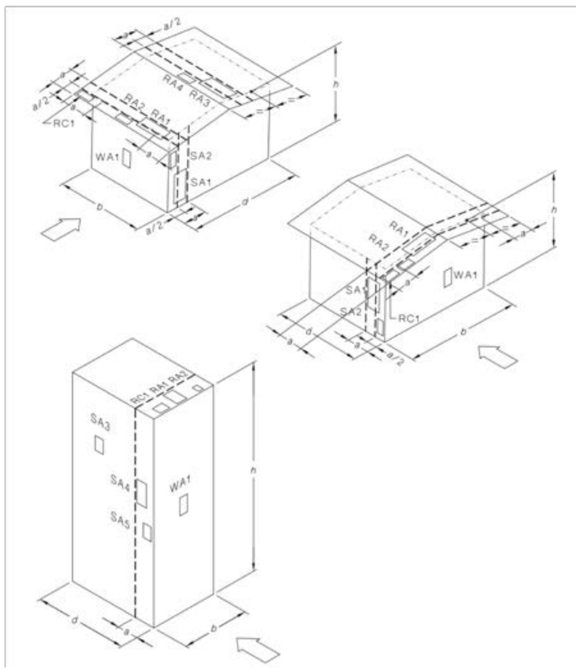

Figure 2. Local Pressure Factors (Standards Australia 2011)

After further evaluation and fixing of the second developed workflow, the third step of the development incorporates an optimization stage in the workflow to allow users to optimize their analysed design model.

5. Background Research

Wind loading codes and standards which emerged in the second half of the twentieth century, have achieved wide acceptance and are often engineers only contact with information for wind-loading calculations. However, as these codes and standards are simplified models from the results of extensive research, perfect accuracy cannot be expected (Holmes, 2015). In every wind loading code and standard, there are four elements that contribute to the overall calculations of the design process for wind loads:

- Specification of a basic or reference wind speed for various locations or zones.
- Adjustment factors for the effects of height and terrain type.
- Aerodynamic shape factor
- Dynamic response factor

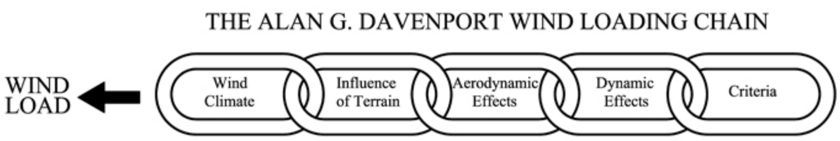

Figure 3. Wind Loading Chain by Alan G. Davenport

5.1. AUSTRALIAN STANDARD AS/NZS 1170.2

The AS/NZS 1170.2, the wind loading standard for Australia, just like the other available standards have the same elements comprising them. In this research, the standard will be focusing more on the aerodynamic shape factor as it is the section of the standard that the workflow is mostly based on.

The section of the standard that focuses on the aerodynamic shape factor allows the users of the standard to calculate internal and external coefficient and other related factors affecting it aside from the aerodynamic shape factor. The aerodynamic shape factor (C_{fig}) which considers the effect of the geometry of a building on the wind load, is a factor that is included in the calculation for the wind pressure. The rules underlying the calculation for the design wind pressure is as follows:

$$p = 0.5\, P_{air}\, V^2_{des,\theta}\, C_{fig}\, C_{dyn} \quad (1)$$

where

p is the design wind pressure
P_{air} is the density of air which is taken as 1.2 kg/m^2
C_{fig} is the aerodynamic shape factor
C_{dyn} is the dynamic response factor

And to calculate the aerodynamic shape factor for both the internal and external pressure, the rules for the calculation are as follows:

For external pressures: $C_{fig} = C_{pe}\, K_a\, K_{ce}\, K_l\, K_p$ (2)

For internal pressures: $C_{fig} = C_{pi}\, K_{ci}$ (3)

where

C_{pe} is the external pressure coefficient
C_{pi} is the internal pressure coefficient
K_a is the area reduction factor
K_l is the local pressure factor
K_p is the porous cladding reduction factor

To determine the value for the factors affecting the calculations of the aerodynamic shape factor, the standard has a set of rules. In order to correctly calculate the aerodynamic shape factor for the internal and external pressure, it is essential for the external and internal pressure coefficient to be determined. For an enclosed rectangular building, the external pressure coefficient is determined using the Tables 5.2 (A) to 5.2(C) for the walls and 5.3(A) to 5.3 (C) for the roofs of the standard. It can be observed that in some cases, two values are given by the tables. For these cases, the value may be subjected to either value and therefore, the roof surfaces of the building should be designed for both values. Alternatively, external pressures are combined with internal pressures to obtain the most severe combinations of actions for the design of the building.

To determine the internal pressure coefficient, much like the external pressure coefficient, values are given from Tables 5.1(A) and 5.1(B). Table 5.1(A) of the standard provides coefficients for buildings with open interior plan and permeable surfaces without dominant openings. On the other hand, Table 5.1 (B) is for buildings with open interior plan and surfaces with dominant openings. The dominant openings mean that it plays a dominant effect on the internal pressure in the building.

However, as shown in the calculation rules above, internal and external coefficients are not the only factors needed for the calculation. Therefore, it is also essential to determine the value of other factors. The standard states that the value of the area reduction factor is always 1, unless it is assessing for the roofs or side walls, in which the value depends on the value of the tributary area, which is defined as the area contributing to the force under consideration. The values for the area reduction factor is given in Table 5.4.

The local pressure factor section in the standard evaluates the wind pressure on small areas. The peak wind pressures often occur on areas near windward edges and roof edges as depicted on the diagrams in the standard. The local pressure factor is applied only in the calculation of claddings, their fixings and members directly associated with it. The rules to determine the local pressure factor is as given in Table 5.6 of the standard.

Another factor affecting the calculation of the aerodynamic shape factor is the combination factor, which accounts for the effects of non-coincidence of peak wind pressures on different surfaces of the building. The values are given in Table 5.5 of the standard. However, it should be noted that this factor does not apply to claddings. Finally, the last factor that needs to be determined is the permeable cladding reduction factor. This factor has taken account the effect of permeable cladding on the pressures as it has been found that negative surface pressures on permeable claddings are lower than those on a similar but non-permeable cladding. The rules to determine this factor is given in Table 5.8 of the standard. It should be noted that this factor is used for negative pressure only when external surfaces consisting of permeable cladding with an open ratio of greater than 0.1 and less than 1. The open ratio of the surface is defined as the ratio of the open area to the total area of the surface.

5.2. COMPARISON OF CFD AND AS/NZS 1170.2

Over the years, even though CFD has a drastic improvement on their functionality and is often used to analyse the impact of wind loads acting on a building, has its own limitations. The main reason to create a workflow that is standard-based is due to the CFD’s lack of ability to assess the local pressure, the wind pressures on small areas. This is due to the lack of ability of CFDs to generate local turbulence and in small scale (Holmes, 2015); and the few CFD software that are able to assess them are very costly and very time-consuming in simulating the results whereas the standard is able to assess the local pressure with less time. Adding on to that, the final outcome generated by the CFD is an average of all the possible results whereas the standard provides results that are at the extremes allowing the users of the standard to anticipate the adverse effect of wind pressures on the building.

Even so, the standard also has its own limitations in that it only analyses rectangular plan models while the CFD can analyse complex design models.

Although each of them has their own limitations and differences, several experiments conducted by engineers have shown that the results generated from both the CFD and AS/NZS 1170.2 are similar and if different not that far off (Parv, Hulea, and Zoicas, 2012).

COMPUTATIONAL FLUID DYNAMICS	AS/NZS 1170.2
• DOES NOT ASSESS LOCAL PRESSURE	• ASSESS LOCAL PRESSURE
• CAN ANALYZE COMPLEX DESIGN MODELS	• ONLY ANALYZES RECTANGULAR PLAN MODELS
• THE FINAL OUTCOME COMES FROM THE AVERAGE OF THE PREDICTIONS	• THE FINAL OUTCOME COMES FROM EXTREME PREDICTIONS
• VERY TIME-CONSUMING	• NOT TIME-CONSUMING

Figure 4. Comparison between CFD and AS/NZS 1170.2

6. Research Project: Workflow Development

The research started with a discussion with the industry partner who wanted to incorporate the Australian Standard: AS/NZS 1170.2 for a wind analysis tool that could help visualize the analysis and optimize the outcome so that the users will be able to get the best solution for locating dominant openings or penetrations on the building design models. By doing so, the users would be able to better understand the results of analysing the design models against the AS/NZS 1170.2. To develop the workflow for the standard-based wind analysis tool, the workflow will be mainly created in Grasshopper with the occasional use of Python.

6.1. STAGE 1: ENABLING USERS TO IMPORT MODELS AND ANALYZE THEM

In order to create a Grasshopper script that calculates the wind load acting on a building, it is essential for any design models to be able to be imported into the workflow without any problem. Consequently, the first step of stage one is to enable users to import their models. Following step one, the next step is to allow users to analyse their design models against the rules of the standard. To begin creating the workflow for this analysis and calculation, it is necessary to understand the factors affecting the calculation for design wind pressure according to the standard. The standard states that to find the design wind pressure, it is required to know the design wind speed, dynamic response factor and the aerodynamic shape factor. However, since the research is focusing more on Section 5 of the standard, which is for aerodynamic shape factor, the workflow is designed so that the design wind speed and dynamic response factor will be inputted by the users themselves. Therefore, the workflow will consist of Grasshopper components that leads to the calculation of the aerodynamic shape factor.

To begin creating the workflow for the calculation, a set of codes containing the rules for determining the numerical value of the factors affecting the aerodynamic shape factor is created. The first set of coding made was to determine the internal and external pressure coefficient, as these two are the main factors needed to calculate the aerodynamic shape factor. Using the rules obtained in the AS/NZS 1170.2 Table 5.3 and 5.2, a set of codes was created using Python scripting. Although the codes for both the internal and external pressure coefficient was complete, it was evident that other factors such as the area reduction factor (K_a) and the local pressure factor (K_l) would be needed to ensure that the aerodynamic shape factor could be calculated. By creating another set of codes using the rules obtained in the AS/NZS 1170.2 Table 5.4, 5.5 and 5.6, a series of components for these factors were created.

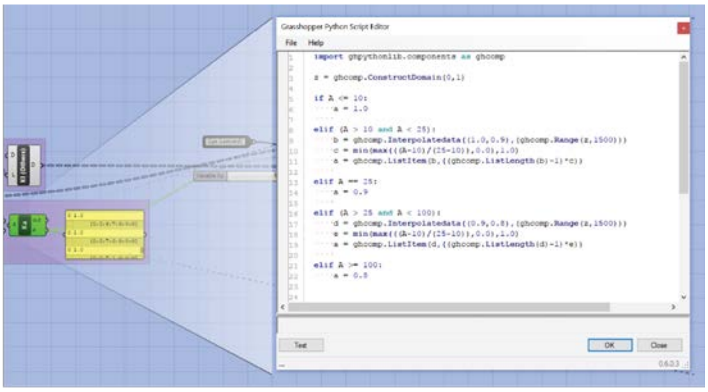

Figure 5. Codes for determining K_a

Adding on to that, two more components which allows users to calculate the aerodynamic shape factor for the internal and external pressure was created with the previously created components as the inputs. Finally, to calculate the design wind pressure, another Grasshopper component is created with the design wind speed, dynamic response factor and aerodynamic shape factor as its input.

6.2. STAGE 2: INITIAL VISUALIZATION METHOD

After the components for calculating the design wind pressure is made, the next stage for the workflow is to allow users to easily visualize the results on the building. By displaying the results, it would potentially allow the users to be informed of the problems from the design of the models and better understand the analysis. To help visualize this, since the design wind pressure is affected by the local pressure factor, it was decided that to visualize the pressure acting on the design model, grids as represented in the rules under the standard on local pressure factor, will be used to calculate the pressure acting on the design model instead of calculating the pressure acting on one whole surface of the model. By using the voxel grids, the analysis and calculation would be more accurate as the value of the pressure resulting from it is located at a specific area of the building instead of a broad area. The grids will also be able to be adjusted according to the size that the user prefers. After adding the function for the grids to the workflow, the numerical results from the calculation is visualized on the building at each grid to aid the users.

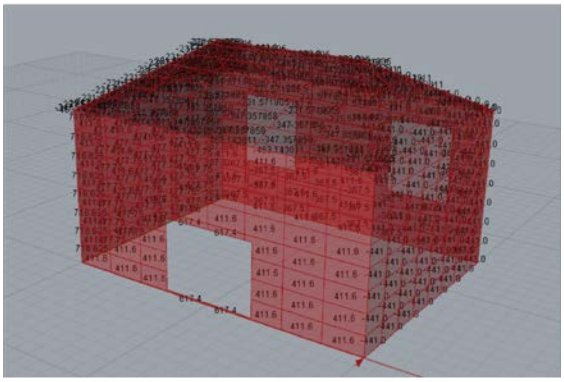

Figure 6. Numerical Visualization

6.3. STAGE 3: APPLYING COLOUR CODINGS FOR VISUALIZATION OF ANALYSIS

After creating the first stage of the workflow and evaluating it, it was clear that the previous method of visualizing the analysed results is not effective. Even though it displays the result to the users, its ability to display the result is not clear and it is difficult to see the numerical values, especially if the number of grids on the surface increases. Furthermore, users with minimal to no knowledge of the standard would not be able to understand when the pressure acting is too high. Therefore, to solve this problem, it is decided that colours will be added to represent the pressure acting on the model. By doing so, users will be able to interpret the results faster and better than with the previous method. To incorporate the new visualizing method, a basic workflow using the gradient and legend component was made. This allows the low pressure acting on the building to be projected in the colour blue and those with high pressure to be projected as red.

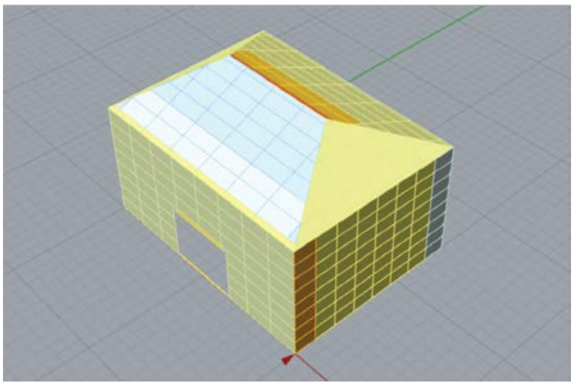

Figure 7. Colour Coded Visualization

6.4. STAGE 4: ENABLING THE IMPORTED MODEL TO BE PARAMETRIC

As discussed in the early stages of the research, the workflow will incorporate an optimization stage in order for the users to get the optimal location for placing the dominant openings or penetrations. To apply this optimization stage, it is essential that the dominant openings and penetrations on the building design model is parametric. However, with the previous workflow, the user is only able to import the model that is static in the Grasshopper environment. If the model is static, the location of the openings and penetrations could not be optimized as there is no input for the optimization stage. Therefore, to improve the previous workflow, it was decided that the dominant openings and penetrations on the design model needs to be made parametric. To achieve this, it was decided that the features of the design model, the dominant openings or penetrations and the overall design model, to be imported separately. To make the models parametric in the environment, a basic script consisting of a few Grasshopper components such as regional difference and surface was created. With this script, users are able to import the model into the Grasshopper environment without them needing an advanced knowledge in Grasshopper.

However, during the evaluation of this script, it was observed that models with a large number of dominant openings or penetrations generate problems during the importing stage. After further evaluation, the problem is caused by a flaw in the Grasshopper script, particularly the regional difference component. To solve this problem, the regional difference component is then replaced by the solid difference component which finally solves the issue.

6.5. STAGE 5: INCORPORATING OPTIMIZATION IN THE WORKFLOW

As a last iteration for the research following the previous developed workflow, the optimization stage is incorporated into the workflow. This was achieved through the introduction of the Grasshopper component Galapagos. This new workflow allows the users to optimize the design model so that the dominant openings or penetrations are placed at the optimal desired location. This would allow the users to improve their design without having to manually fix the design models. During the implementation of the component into the script, it was observed that during the optimization process, there was a problem in the iteration for the optimized results. As constraints have not been implemented into the Galapagos component, there are solutions that have the dominant openings located away from the model. Therefore, in the attempt to solve this solution, the input for the component is given constraints to lock the optimized solution to be located on the design model.

7. Evaluation and Limitations of Research Project

Despite the attempt to create a perfectly working standard-based wind analysis tool, the research fell short for various reasons. Firstly, with the given time frame, it is only achievable to incorporate one section of the standard into the workflow which leads to the reduced accuracy in the calculation. Adding on to that, only foundational research such as the creation of a grasshopper script, is achieved. Secondly, since the workflow is created in Grasshopper, the workflow is limited to be used for users with basic knowledge in the tool. Finally, due to the lack in the ability in programming and advanced visual scripting, the workflow created for the tool is rather inefficient causing unnecessary lags when the tool is operated.

8. Significance of Research

It could be concluded that the research provides an initial step as a tool to analyse wind loads acting on the building design models through the rules set by the Australian Standard: AS/NZS 1170.2. The incorporation of the standard’s rules into the workflow of a wind analysis tool could potentially reduce the use of CFD software in situations when it is not needed which consequently reduces the time and cost used for simulations.

Despite the lack of ability for the research to reach the original desired outcome, it is clear that the workflow created in the research could analyze simple design models that could aid non-engineers in understanding the analysis using the standard.

9. Conclusion

This paper outlines the use and value of computational tools in assisting in the creation of a wind analysis tool that incorporates the AS/NZS 1170.2. From the results of the research, further research is recommended to further develop the workflow so that it could also assess the design models much faster and add on the other sections from the standards as well as improve the workflow so that the analysis and calculations from the workflow of the wind analysis tool will be more accurate. Designing this workflow will help architects understand the impact of wind pressure on their design and help them make more informed decisions on where the dominant openings or penetrations should be placed in a building at the early design stages as well as help them assess their models with minimal knowledge or understanding of the AS/NZS 1170.2. Additionally, this workflow can act as a bridge between wind engineers and architects as it improves their communication.

Acknowledgements

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